

Humidity influence on switching-impulse breakdown voltage of air gaps for indoor high-voltage installations

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Abstract : For inhomogeneous fields like in many practical insulation configurations, the switching-impulse breakdown voltage of a given air-gap usually decreases with the decrease of atmospheric humidity. A correction procedure recommended by IEC is commonly used for converting the measured voltage or the test voltage from non-standard to standard reference atmosphere, or vice versa. The applicability of the humidity correction on relative uniform gap is not clear. In this paper results from newly performed laboratory test on air gaps of different uniformity under different atmosphere are presented. Comparison is made between the outcomes of the IEC recommended corrections for these results.

Key Words : High-voltage insulation, High-voltage testing, Air gaps, Atmospheric conditions.

INTRODUCTION

For inhomogeneous fields like in many practical insulation configurations, the switching-impulse breakdown voltage of a given air-gap usually decreases with the decrease of atmospheric humidity. The phenomenon behind is complicated and is influenced by the gap structures, i.e. the electric field distribution and the type of discharges. A large number of contributions on these subjects exist in literature and have been well covered in the Cigré reviews [1][2]. For a uniform gap, the effect of humidity on the breakdown voltage is negligible. For non-uniform gaps such as rod-plane like gaps the influence of humidity is found to be of significant. From quasi-uniform gaps to non-uniform gap the level of humidity influence is not very clear. A correction procedure recommended by IEC is commonly used for converting the measured voltage or the test voltage from non-standard to standard reference atmosphere, or vice versa [3]. This correction procedure was obtained by a semi-physical model and by laboratory test results on, mostly, rod-plane type of gaps. The applicability of the humidity correction on relative uniform gap is no clear. For the indoor high-voltage installation, the shape of the electrode is often modified to obtain a more compact design than the case that a rod-plane gap will be used. It is therefore important to verify the accuracy of the recommended correction for these cases.

In this paper results from newly performed laboratory

test on air gaps of different uniformity under different atmosphere are presented. These results were then corrected into the standard reference conditions. Comparison is made between the outcomes of the IEC recommended corrections for these results.

LABORATORY TESTS

Test Conditions

The tests were performed at STRI. A climate chamber was used in order to control the air temperature and humidity. The inner dimension of the climate chamber is 3050×2950×5000 mm (width × length × height). The test voltage is connected into the climate chamber via a wall bushing installed on the ceiling of the chamber. Switching impulse of 400 kV can be applied through this bushing to test objects inside the climate chamber. Fig.1 is the front view of the chamber.

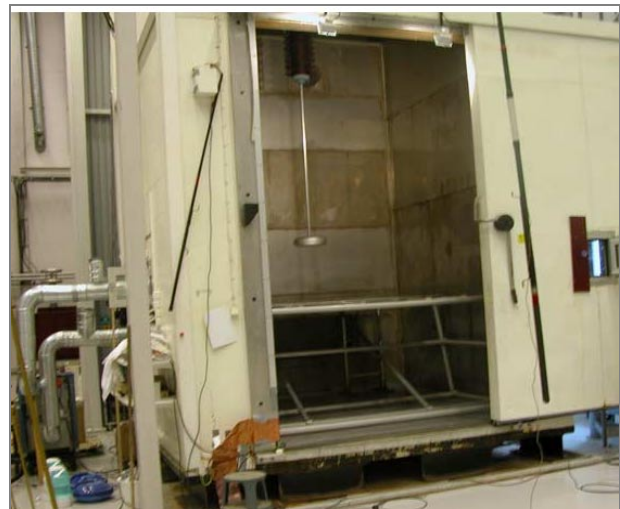


Figure 1. Front view of the climate chamber with door opened

The chamber is built with well-isolated walls. Originally, the chamber is equipped with the temperature control in the range of -55°C to $+70^{\circ}\text{C}$. For this study, a humidity regulation system was developed and installed with both air dryer and humidifiers included. This regulation system enables a stable humidity level inside the chamber. The humidity level is controllable. This system has been tested to be able to reach a low level of 0.6 g/m^3 in absolute humidity at air temperature of 20°C .

The humidity was measured by a commercially available Dew-point Meter of type Vaisala DRYCAP® Hand-Held Dew-point Meter MD70. It is connected with a probe of type MDP74B. The probe can be operated at a temperature range of -10°C to $+60^{\circ}\text{C}$. The accuracy of this measuring equipment, as given in the product specification, is $\pm 2^{\circ}\text{C}$ at a dew-point between dew-point temperatures of -60°C to $+20^{\circ}\text{C}$. A special calibration was requested when the instrument was purchased. This calibration resulted in an improved measuring accuracy to the level of, e.g., 0.4°C at a dew-point of -16°C .

Test Objects

The air gaps used in the tests were rod-plane, sphere-plane and two toroid-plane gaps. All gaps tested were of a gap distance of 600 mm. The geometrical parameters of these gaps are given in Fig. 2.

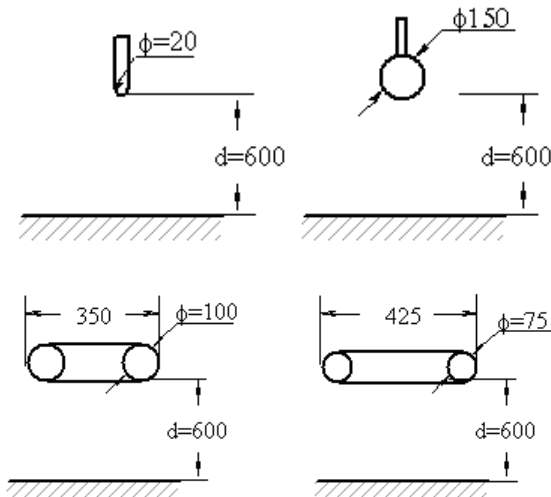


Figure 2. Geometrical parameter of the tested air gaps

The rod electrode has a half-spherical end and the rod diameter is 20 mm. The diameter of the sphere electrode is 150 mm. The sphere was installed on the end of an aluminium tube of 30 mm in diameter. Two toroid electrodes were used. The outer diameter of the toroid and tube diameter of the toroid are 350 and 100mm for one toroid; 425 and 75 mm for the other toroid respectively. The toroid electrodes are covered in the centre. During the tests, the toroid was connected to the end of an aluminium tube of 30 mm in diameter. Fig. 3 is the photograph of the electrodes used.

Test Methods

The test voltage was standard switching-impulse (250/2500). The test was performed with the up-and-down procedure with minimum 30 valid voltage applications at each voltage level. The voltage level of 50% breakdown probability and the conventional deviation were then evaluated from the tests. The test voltage was applied after the air temperature and humidity in the chamber had been stabilized and

measured. A video camera was used to inspect and record the tests through a window on the chamber. The air temperature and humidity inside the chamber were also measured directly after each test.

Tests were performed at different atmospheric conditions for each electrode used. It takes certain time to reach a stable humidity level in the chamber, typically one hour or more. Therefore, to save time, several tests were performed at the room condition that is close to the standard reference conditions, but not exact.



Figure 3. Electrodes used in the tests

Test Results

The tests performed are listed in table 1-4. Given in the same tables, for each atmospheric condition, is the 50% breakdown voltage, U_{50} , the conventional deviation, σ , evaluated from the test results under this condition. Corrections were made for these U_{50} values according to IEC recommended procedure. The corresponding value of U_{50} at the standard reference conditions, after the correction, $(U_{50})_0$, is also given in the table.

Table 1 Results from rod-plane gap

Pressure, (mbar)	982	993	978	962
Temperature, ($^{\circ}\text{C}$)	20.4	22	55	54.8
Humidity, (g/m^3)	1.05	7.58	1.06	10.5
U_{50} , (kV)	279	294	242	274
σ , (%)	2.4	2.8	4.1	1.5
$(U_{50})_0$, (kV)	320	312	311	319
Difference in $(U_{50})_0$, (%)	2.5	0	0	2.2

Table 2 Results from sphere-plane gap

Pressure, (mbar)	967	967	966
Temperature, (°C)	19.5	19.3	55
Humidity, (g/m ³)	1.0	8.0	1.3
U ₅₀ , (kV)	267	289	237
σ, (%)	1.1	5.3	1.4
(U ₅₀) ₀ , (kV)	311	311	307
Difference in (U ₅₀) ₀ , (%)	0	0	-1.3

Table 3 Results from toroid (350/100) -plane gap

Pressure, (mbar)	933	966	966	969
Temperature, (°C)	20	20.8	20	55.6
Humidity, (g/m ³)	0.85	6.4	11.1	0.9
U ₅₀ , (kV)	354	351	354	312
σ, (%)	4.6	2.0	1.5	1.7
(U ₅₀) ₀ , (kV)	389	383	369	393
Difference in (U ₅₀) ₀ , (%)	5.4	3.4	0	6.5

Table 4 Results from toroid (425/75) -plane gap

Pressure, (mbar)	1000	991	985	1003
Temperature, (°C)	20.2	19.8	20	54.5
Humidity, (g/m ³)	0.8	4.0	11	1.0
U ₅₀ , (kV)	339	335	337	303
σ, (%)	2.1	1.0	1.0	1.1
(U ₅₀) ₀ , (kV)	377	368	346	375
Difference in (U ₅₀) ₀ , (%)	9.0	6.4	0	8.4

HUMIDITY CORECTION

IEC Recommended Procedure

In the IEC recommended procedure [3], the standard reference atmosphere is at a temperature of 20 °C, pressure of 1013 mbar and an absolute humidity of 11 g/m³. An U₅₀ value measured at a different atmospheric condition is corrected to the standard reference condition by divide the U₅₀ with a correction factor, k_r . This correction factor is consisted of a correction related mainly to air density, $k_1 = \delta^m$, and a correction related mainly to air humidity, $k_2 = k^w$. Both exponents in these formulas, m and w , are a function of g , i.e. $m = f(g)$; and $w = f(g)$. In these relations, g is a dimensionless parameter related to the stress level of the gap in concern, $g = U_{50} / (500L \delta k)$.

Two issues are worthwhile to be mentioned at this stage. Firstly, in case no tests have been performed, the accuracy of the estimated U₅₀ of the air gap in concern can have an importance influence on the accuracy of the correction. This is because that the value of g is depending on the value of U₅₀. Secondly, mathematic formulas are given in the Cigré documents, [1], [2], for $w = f(g)$ at different range of g values. These formulas do not coincide with the curves in the IEC standard. However, the corrections by means of the curve for $w = f(g)$, given by IEC or by means of the formulas given by Cigré lead to ignorable, <1%, difference for the test values in this study.

Corrections for The Test Results

In table 1-4, comparison is made between the values of (U₅₀)₀ obtained at various atmospheric conditions for the same gap. In each table, one test performed under an atmospheric condition that is closer to the standard reference condition is marked with bold text. The value of (U₅₀)₀ obtained in this test is taken as the reference test value. The values of (U₅₀)₀ obtained from other atmospheric conditions for the same gap are compared with values of the reference test. The differences are given in the table in percentage. If the correction is accurate, all the values of (U₅₀)₀ for the same gap should be the same with only marginal errors.

One can observe from table 1-4 that, for the rod-plane and the sphere-plane gap tested, the differences in the values of (U₅₀)₀ for different humidity levels are small from engineering application point of view. However, for the results from the two toroid-plane gaps, more significant differences exist.

In table 5-6, the test results from the two toroid-plane gaps are further compared. In these two tables, after the test conditions and the measured U₅₀, the correction factors k_1 and k_2 are also given. The values of U₅₀ are, at first, divided only by k_1 to get the partially corrected values, (U₅₀)_{k1}. The values of (U₅₀)_{k1} at different atmospheric conditions are compared to the value obtained in the reference test. The differences are given in percentage. The second step is to divide (U₅₀)_{k1} with k_2 and making again the comparison. It is indicated through these steps as shown the two tables, that the errors in the correction are mainly contributed by the correction for humidity, k_2 .

CONCLUSIONS

The test results indicate that for relative uniform air-gaps, an over-correction can be obtained for humidity effects following the existing procedure recommended in the IEC standard. Further studies are necessary to obtain more accurate corrections for such cases. This subject is of special importance for the indoor high-voltage installations where a compact design is often required.

Table 5 Results from toroid (350/100) -plane gap

Pressure, (mbar)	933	966	966	969
Temperature, (°C)	20	20.8	20	55.6
Humidity, (g/m ³)	0.85	6.4	11.1	0.9
U ₅₀ , (kV)	354	351	354	312
k ₁ =δ ⁿ	0.980	0.951	0.953	0.850
(U ₅₀) _{k1} , (kV)	361	369	371	367
Difference in (U ₅₀) _{k1} , (%)	2.7	-0.5	0	1.1
k ₂ =k ^w	0.928	0.964	1.006	0.934
(U ₅₀) ₀ , (kV)	389	383	369	393
Difference in (U ₅₀) ₀ , (%)	5.4	3.4	0	6.5

Table 6 Results from toroid (425/75) -plane gap

Pressure, (mbar)	1000	991	985	1003
Temperature, (°C)	20.2	19.8	20	54.5
Humidity, (g/m ³)	0.8	4.0	11	1.0
U ₅₀ , (kV)	339	335	337	303
k ₁ =δ ⁿ	0.987	0.979	0.972	0.886
(U ₅₀) _{k1} , (kV)	343	342	347	342
Difference in (U ₅₀) _{k1} , (%)	-1.2	-1.4	0	-1.4
k ₂ =k ^w	0.910	0.931	1.003	0.910
(U ₅₀) ₀ , (kV)	377	368	346	375
Difference in (U ₅₀) ₀ , (%)	9.0	6.4	0	8.4

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REFERENCES

- [1] Cigré Task Force 07.03 of Study Committee 33. Humidity influence on non-uniform field breakdown in air. *ELECTRA*, N° 134, pp.63-89
- [2] N. L. Allen, J. R. Fonseca, H. J. Geldenhuys and J. C. Zheng. Influence of air humidity on the dielectric strength of external insulation. *Cigré Brochure 72, Guidelines for the evaluation of the dielectric strength of external insulation, Working Group 07 of Study Committee 3*. pp. 59-72
- [3] IEC 60060-1. High-voltage test techniques, Part 1: General definitions and test requirements. Second edition, 1989-11.